Nuclear Effects at an EIC

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1. Some general questions
2. Specific calculation - arXiv:1512.03111 w Matt Sievert & Venugopalan

General Questions

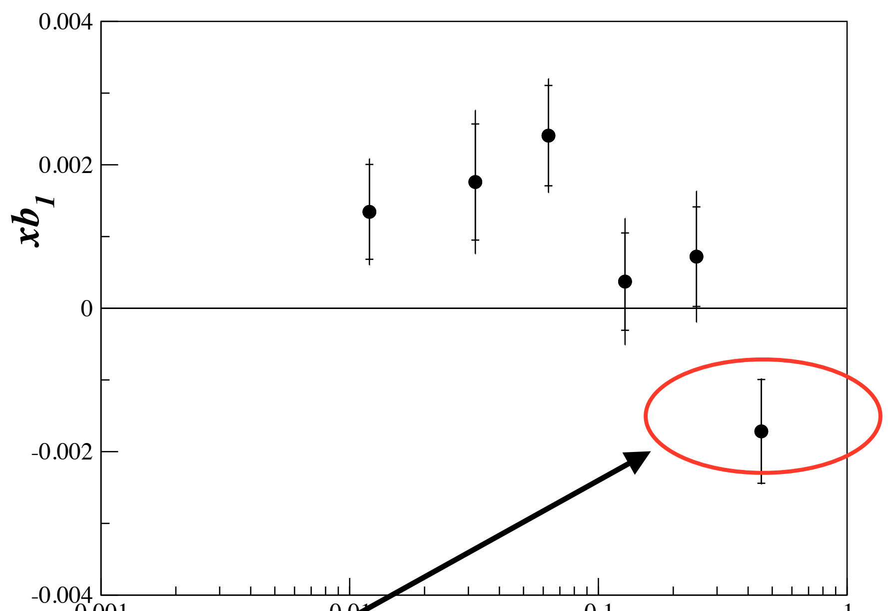
- EIC white paper- Understanding the glue that binds us all. How does binding depend on the glue?
- What IS the relation between gluons and the nuclear binding energy?
- Does such a relation depend on on $G_A(x,Q^2)$ or on something else?
- Does nuclear binding depend on low x?
- Can a relation such be studied at an EIC?

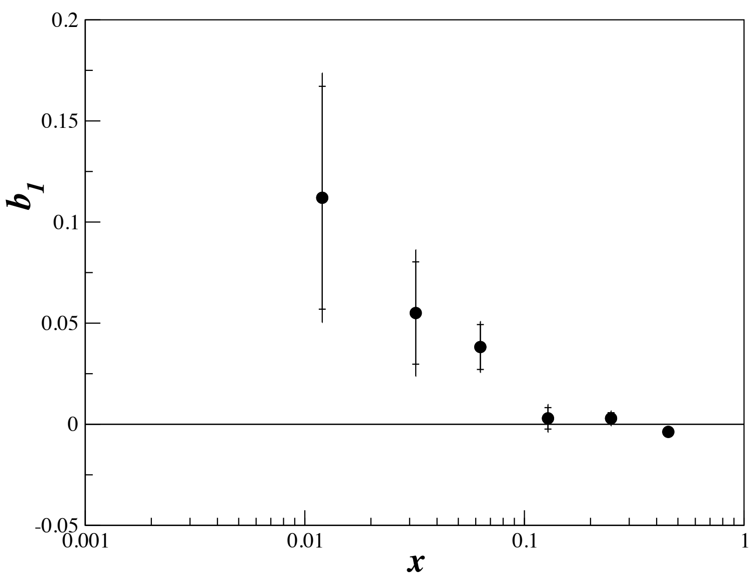
Motivation for the specific:Deuteron Hidden-Color, Six-Quark Contributions to the Deuteron b1 Structure Function arXiv:1311.4561v1

HERMES

C. Riedl, Ph. D thesis, DESY-THESIS-2005-027 (2005).

A. Airapetian *et al*., Phys. Rev. Lett. **95**, 242001 (2005).





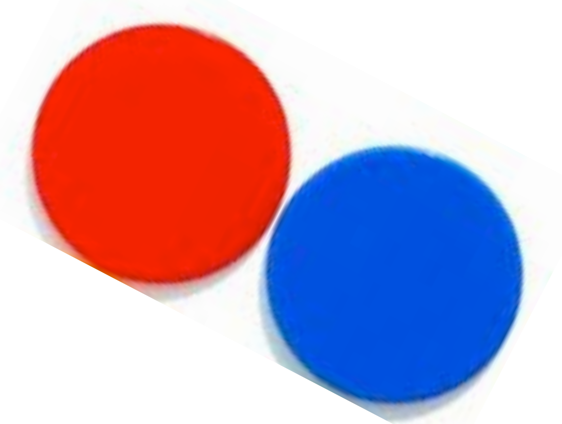
High x -valence quark effect

Not future EIC measurement

JLab proposal PR12-13-011 K. Silfer et al

Hidden color, 6-quark states

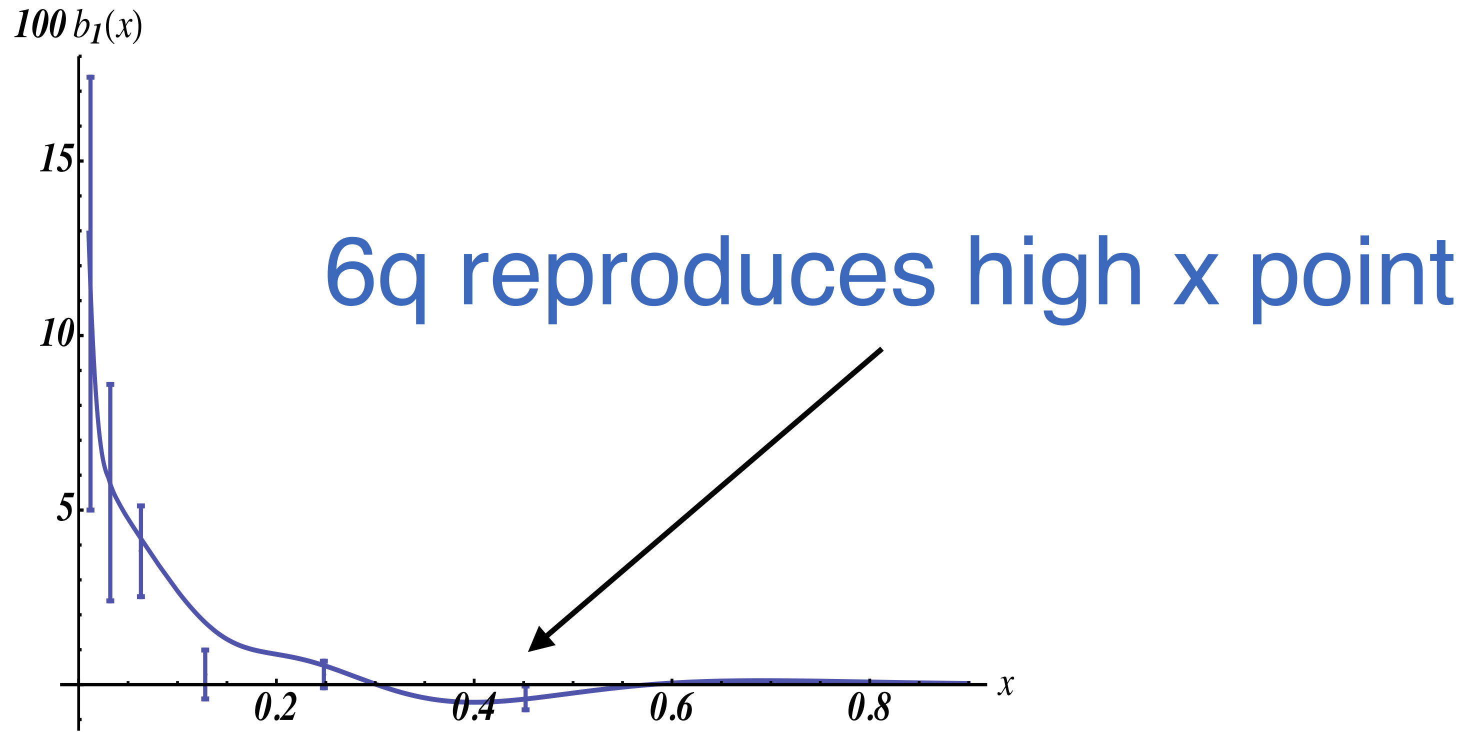
- Maybe deuteron has non-nucleon baryonic components
- 6 quark contribution ~orthogonal to two nucleons
- Dominated by hidden color (two color octets form a color singlet Harvey NPA32, 301
- 6 quarks in same s state wave function:



$$|6q\rangle = \sqrt{1/9}|N^2\rangle + \sqrt{4/45}|\Delta^2\rangle + \sqrt{4/5}|CC\rangle.$$

Review: Bakker and Cheung **Prog.Part.Nucl.Phys. 74 (2014)**

pionic and 6q contributions



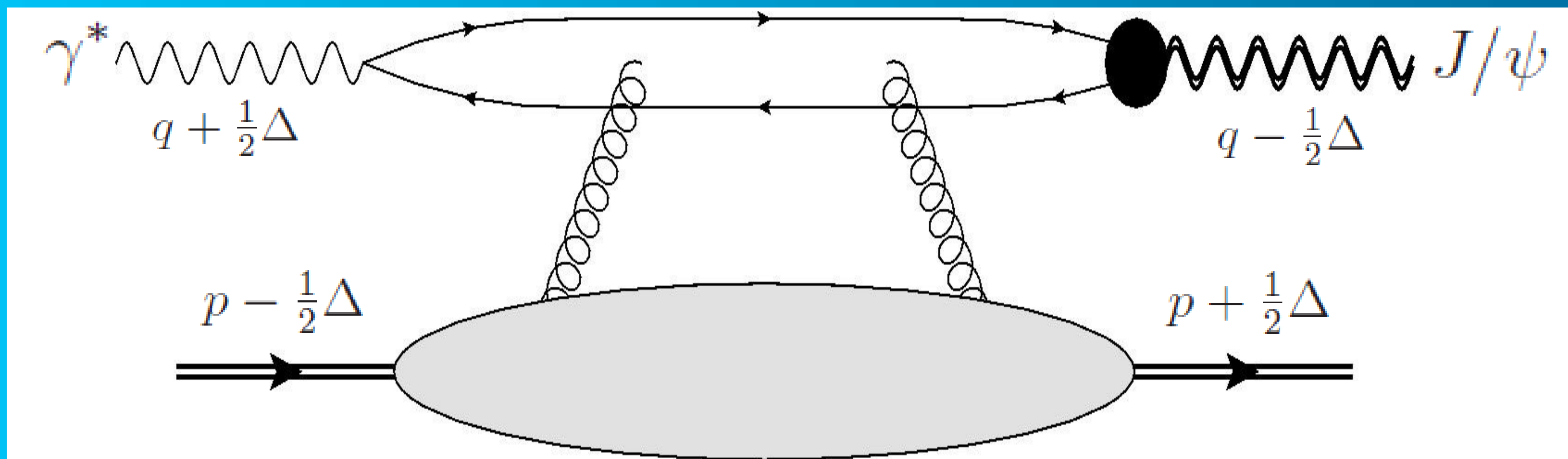
$\langle x\rangle$	$\langle Q^2\rangle$ [GeV^2]	b_1 [10^{-2}]	$\pm\delta b_1^{\rm stat}$ [10^{-2}]	$\pm\delta b_1^{\rm sys}$ [10^{-2}]	b_1^π[29] [10^{-2}]	b_1^π[35] (1) [10^{-2}]	b_1^π[35] (3) [10^{-2}]	b_1^{6q} [10^{-2}]
0.012	0.51	11.20	5.51	2.77	10.5	15.5	24.1	0.00
0.032	1.06	5.50	2.53	1.84	5.6	6.8	8.9	0.00
0.063	1.65	3.82	1.11	0.60	4.2	3.7	4.1	0.00
0.128	2.33	0.29	0.53	0.44	1.6	1.3	1.3	0.01
0.248	3.11	0.29	0.28	0.24	-0.55	.13	0.12	0.41
0.452	4.69	-0.38	0.16	0.03	-0.02	-0.02	-0.022	-0.38

Can reproduce data, so far
JLab experiment needed to test
no other known mechanism contributes at the higher values of x

Phys.Rev. C89 (2014) 4, 045203

See hidden color at EIC?

Step 1 Diffraction at HERA



Hard Exclusive Meson Production at small-x

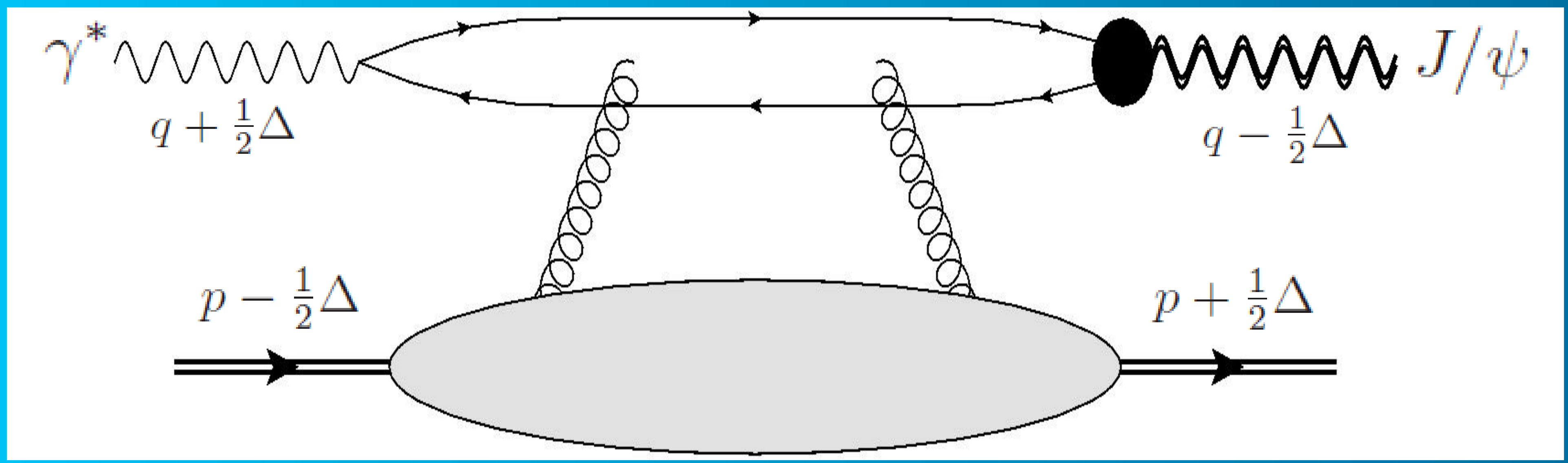
Separation of time scales

Separation of transverse length scales

- Dipole size controlled by Q^2 and heavy quark mass $r_\perp \sim min\left(\frac{1}{Q}, \frac{1}{m_c}\right)$
- Small dipole scatters in the long-wavelength gluon field of the nucleon. $r_\perp \ll \lambda_g$

See hidden color at EIC?

Step 1 Diffraction at HERA



Factorization: Small dipole measures the gluon field of the nucleon

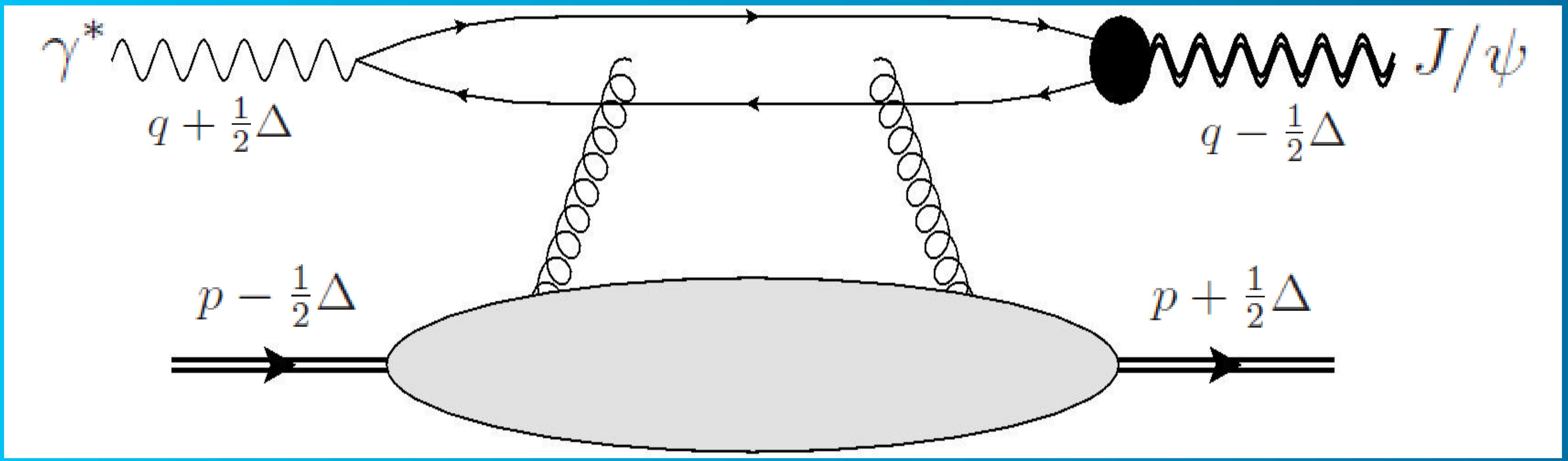
- Dipole wave functions times a universal matrix element
- Generalized Parton Distribution (GPD) – xG in the forward limit

$$\int d\zeta^- \, e^{ixp^+\zeta^-} \left\langle p - \tfrac{1}{2}\Delta \right| F^{+ia}(-\tfrac{1}{2}\zeta) F^{+ia}(+\tfrac{1}{2}\zeta) \left| p + \tfrac{1}{2}\Delta \right\rangle$$

- Small dipole scatters in the long-wavelength gluon field of the nucleon. $r_\perp \ll \lambda_g$

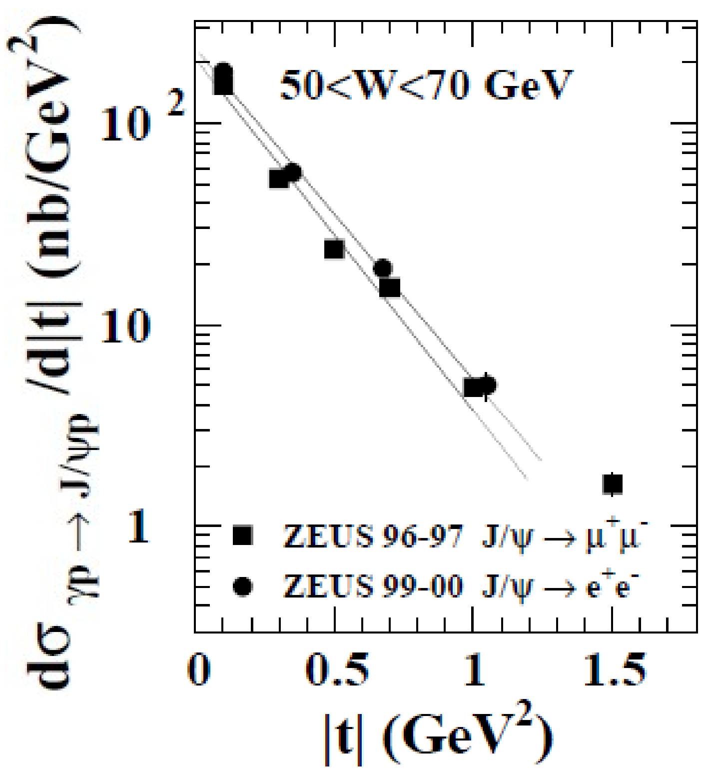
See hidden color at EIC?

Step 1 Diffraction at HERA

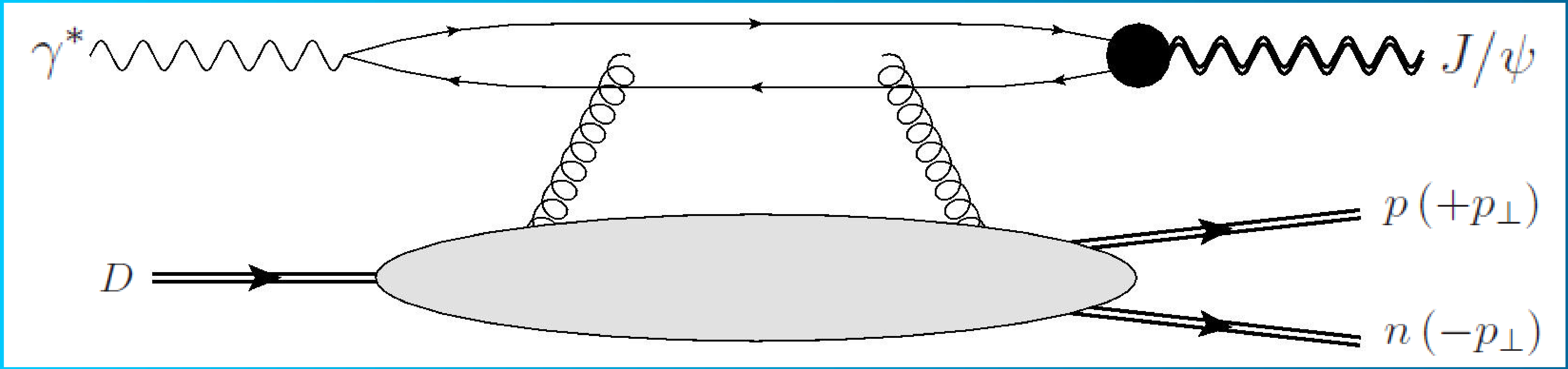


Measured at HERA

- Ample statistics
- Exponential dependence



Step 2 Deuteron Breakup



Hard Exclusive Meson Production on a Deuteron Target

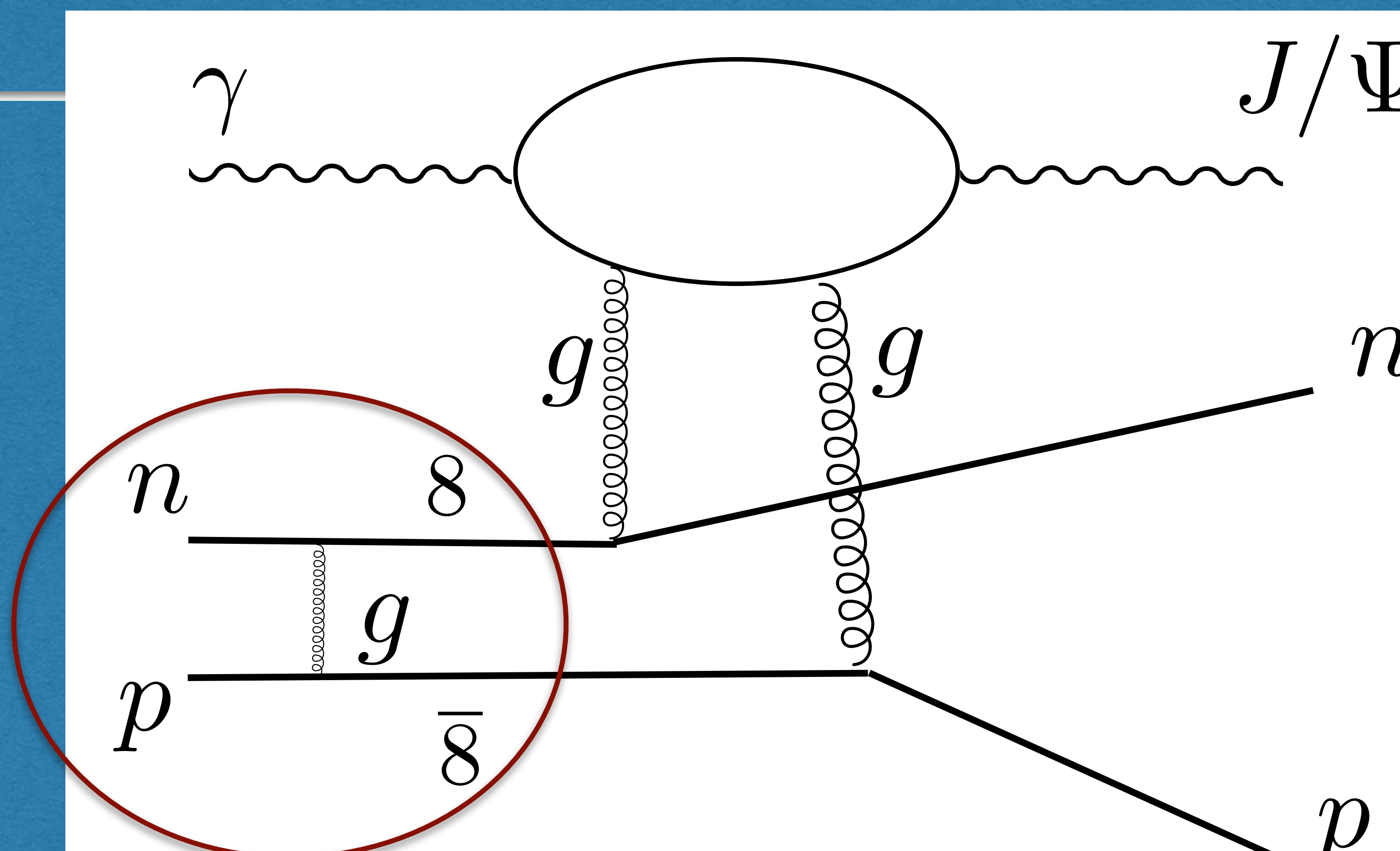
$$\int d\zeta^- \, e^{ixp^+\zeta^-} \, \langle pn\,(p_\perp)|\, F^{+ia}(-\tfrac{1}{2}\zeta)F^{+ia}(+\tfrac{1}{2}\zeta)\,|D\rangle$$

- Same factorization into dipole WF and gluon matrix element.
- Gluon operator as a transition matrix element from the deuteron to NN state
- “Transition GPD”

Final neutron and proton momentum $\perp$ to photon momentum

High $p_\perp$ provides unique look at nucleon-nucleon interactions

Hidden color in Deuteron

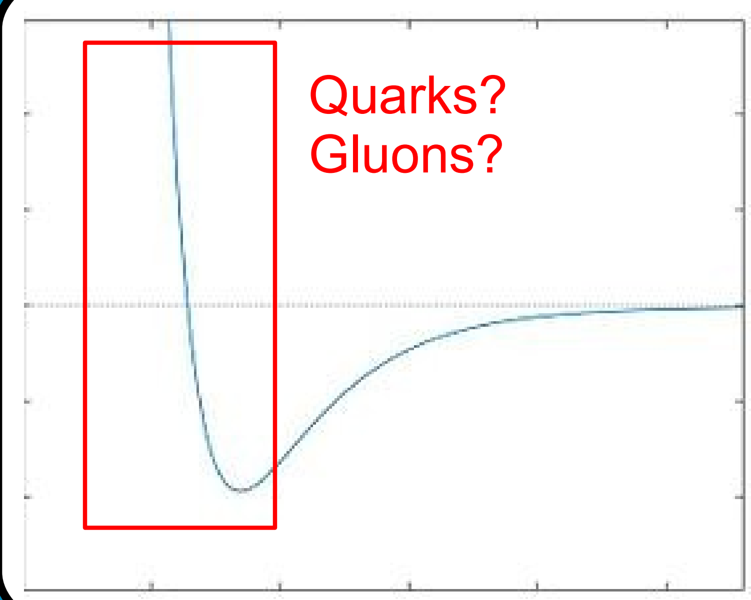


This effect seems very small for large $p_\perp$ -too many propagators

Studying the Short-Distance Nuclear Force at the EIC

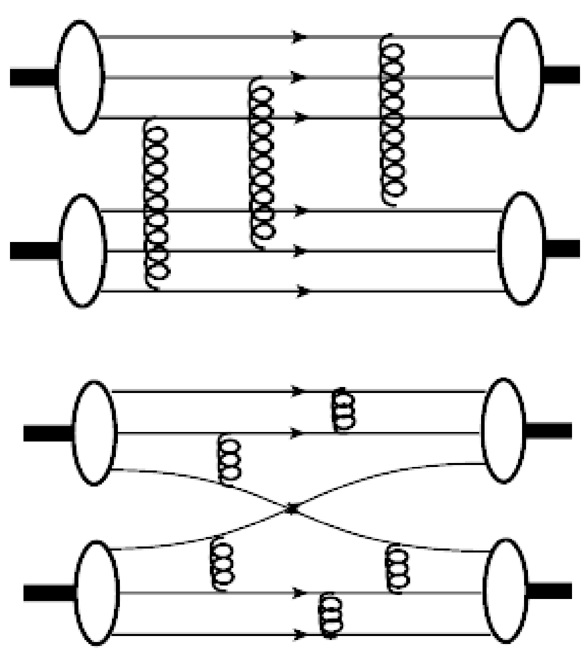
1. arXiv:1512.03111 w Sievert & Venugopalan

- What is the role of QCD degrees of freedom in the core of the nuclear potential?



- QCD power counting suggests hard NN scattering should be dominated by gluon exchange (Landshoff mechanism). Botts Sterman 1989
- But experiment shows a strong preference for quark exchange (Brodsky-Farrar mechanism). Why?

Long standing questions origin of high t scattering



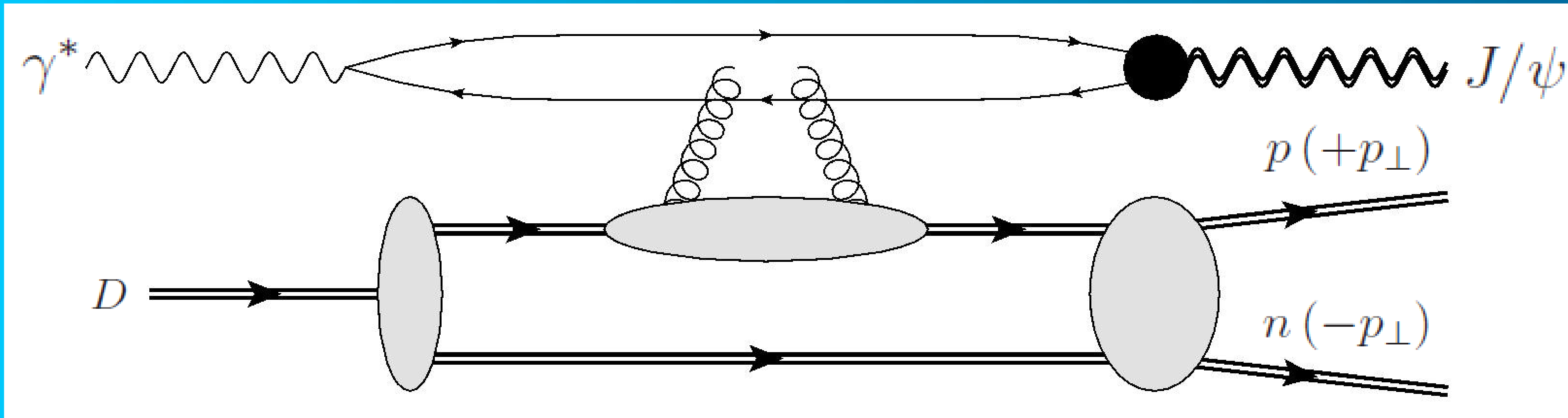
Landshoff

$$\frac{d\sigma}{dt} \sim \frac{1}{s^8}$$

Brodsky-Farrar

$$\frac{d\sigma}{dt} \sim \frac{1}{s^{10}}$$

"Conventional" Nucleon-Nucleon Scattering



One nucleon diffracts, the other is a spectator

- Diffractive scattering is the same as at HERA.

$$\gamma + N \to J/\psi + N$$

- NN pair scatters in the final state and emerges back-to-back.

$$s_{NN} \approx p_\perp^2 \ll s$$

NN scattering as final state interaction

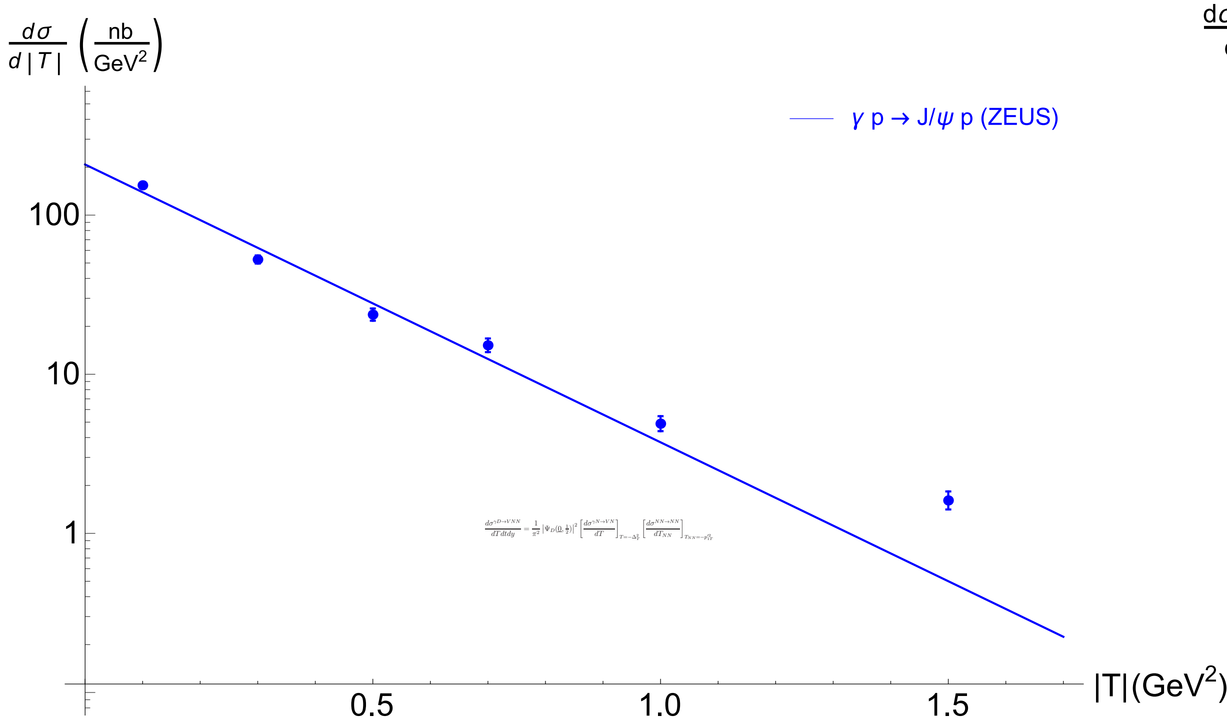
Can make reasonable estimates using known cross sections

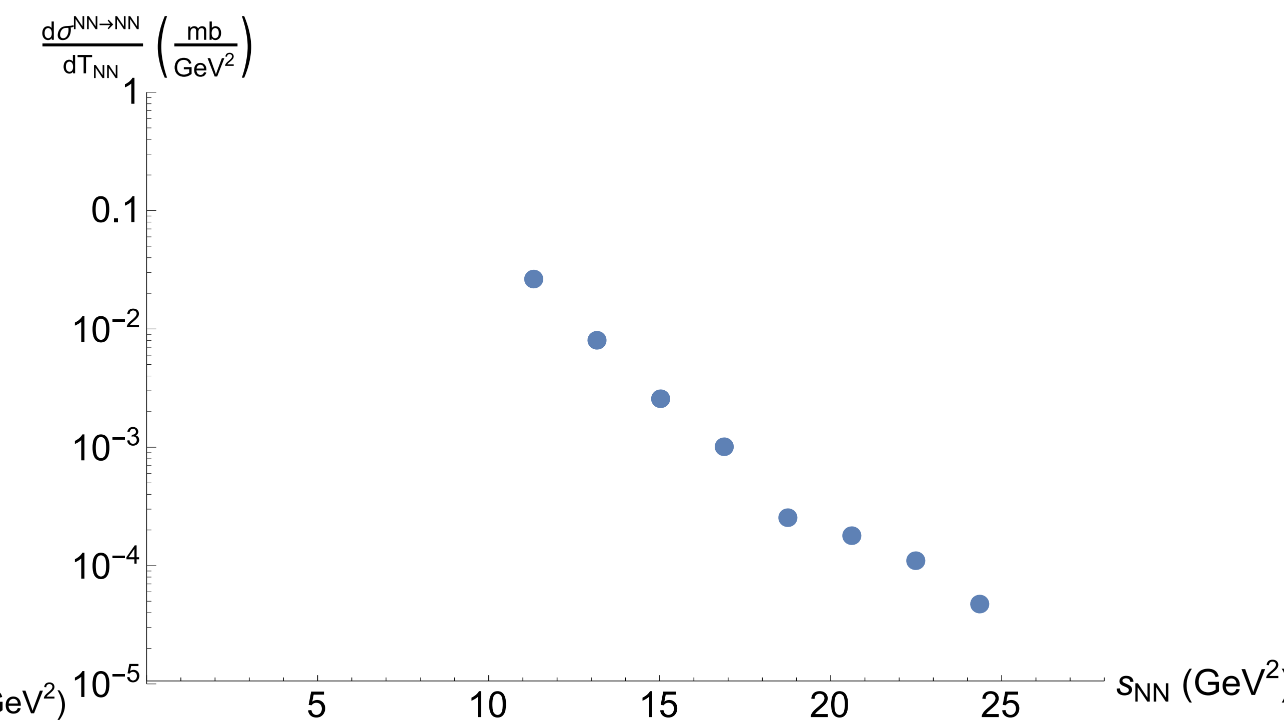
Numerics arXiv:1512.03111

Inputs:

$$\gamma + p \to J/\Psi + p$$

High angle np scattering

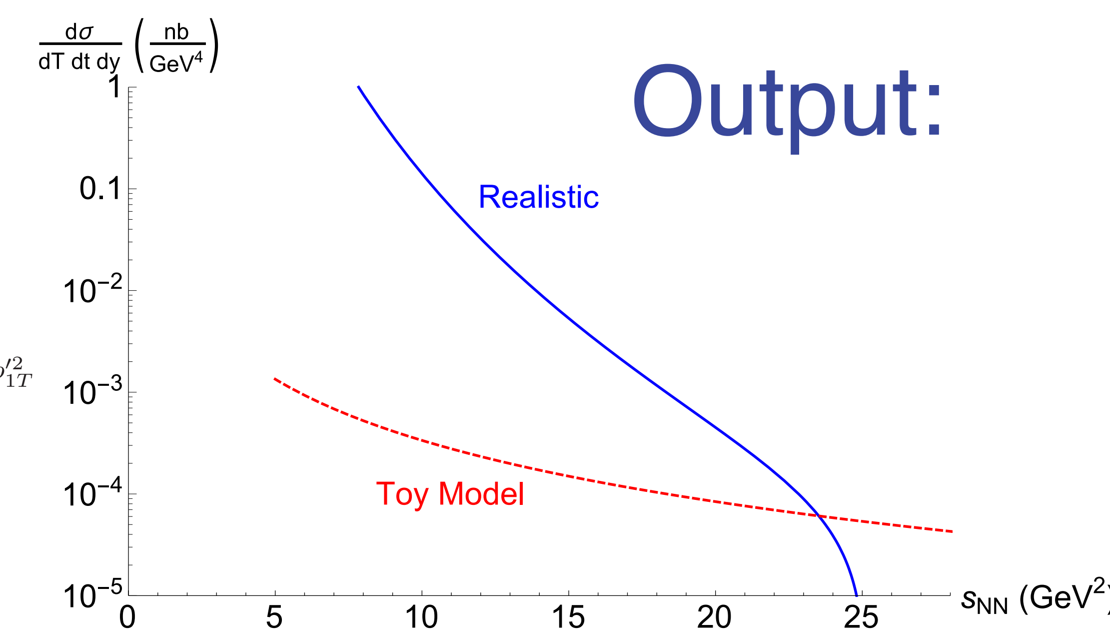


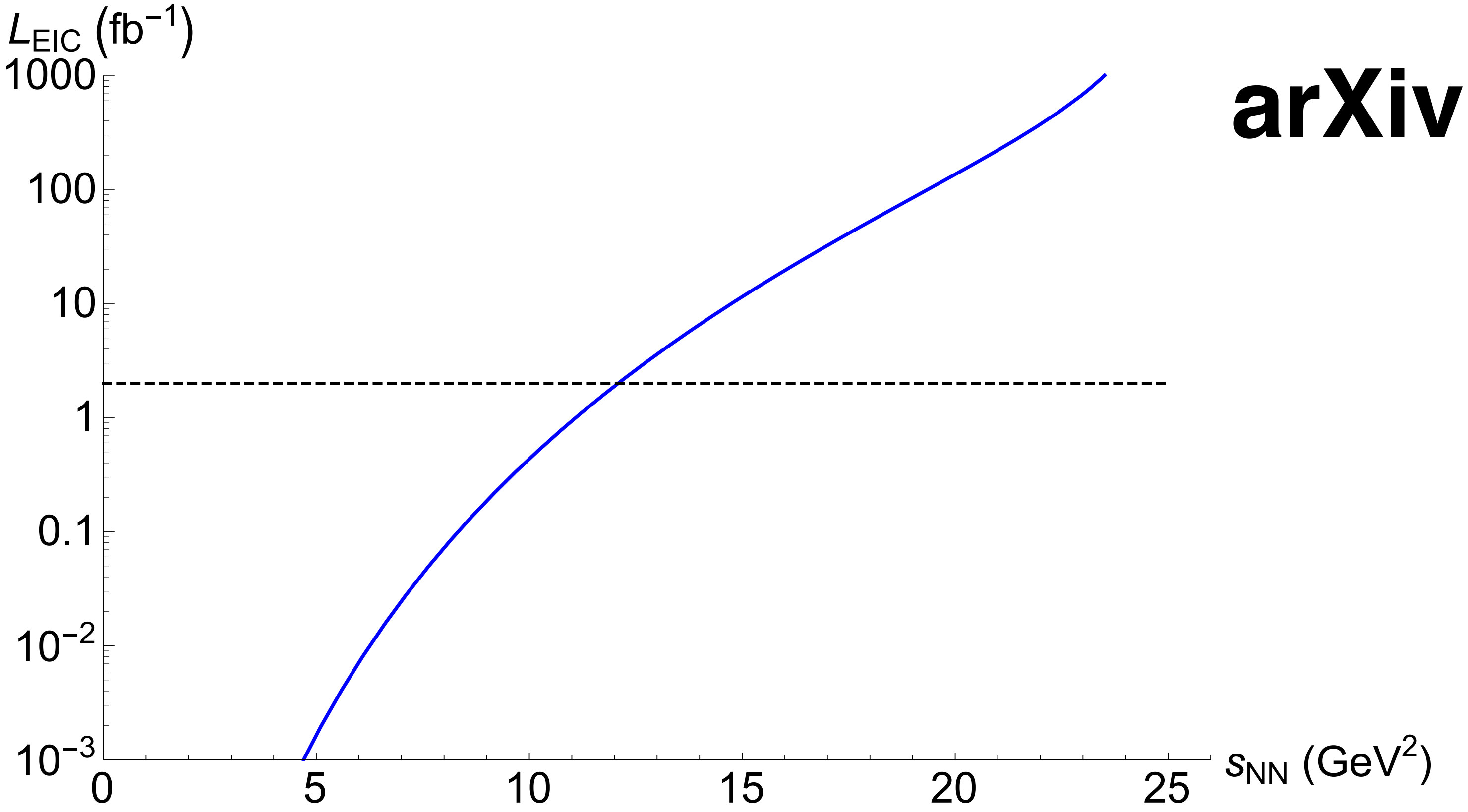


$$\gamma + D \to J/\Psi + n(p_\perp) + p(-p_\perp)$$

$$\frac{d\sigma^{\gamma D\to VNN}}{dT\,dt\,dy} = \frac{1}{\pi^2}\left|\Psi_D(\underline{0},\tfrac{1}{2})\right|^2 \left[\frac{d\sigma^{\gamma N\to VN}}{dT}\right]_{T=-\Delta_T^2} \left[\frac{d\sigma^{NN\to NN}}{dT_{NN}}\right]_{T_{NN}=-p'^2_{1T}}$$

Output:



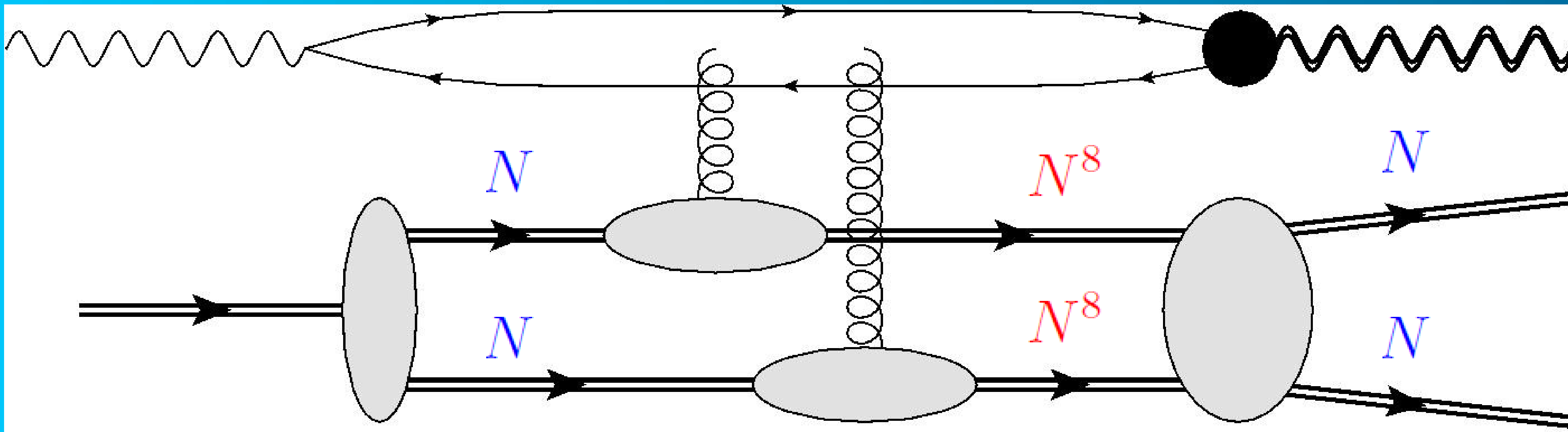


arXiv:1512.03111

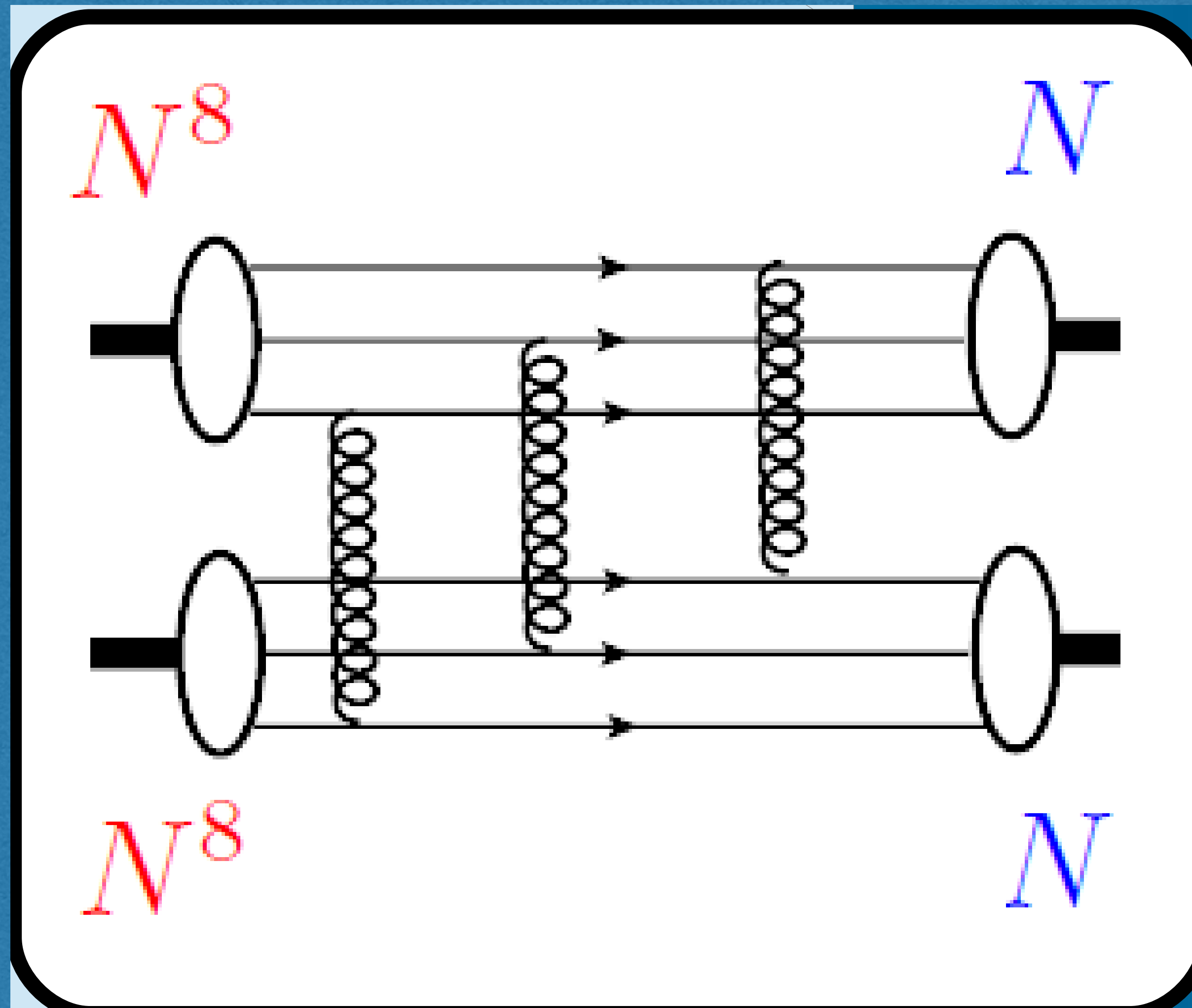
FIG. 17. Integrated luminosities at an EIC needed to detect J/Ψ production in the deuteron breakup process with a given NN invariant mass s_{NN}. With statistics from 20 weeks of running assuming a luminosity of $\sim 1.6 \cdot 10^{32}/\text{cm}^2/\text{sec}$ (black dashed line), a reasonable reach of $\sim 12\ \text{GeV}^2$ can be obtained.

Condition- statistical accuracy should be as good as HERA for diffractive J/Psi photoproduction at their largest t

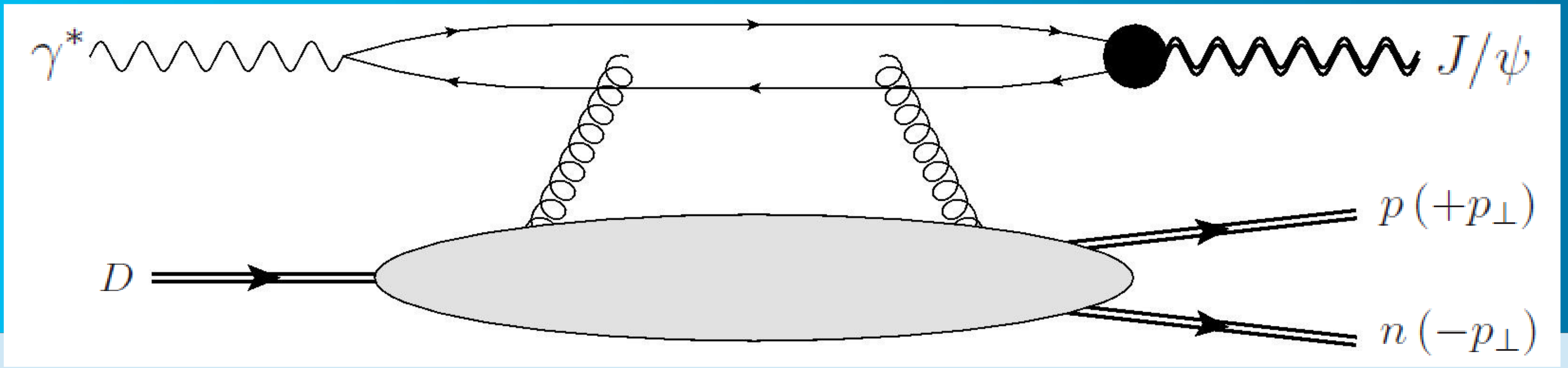
"Exotic" Nucleon-Nucleon Scattering



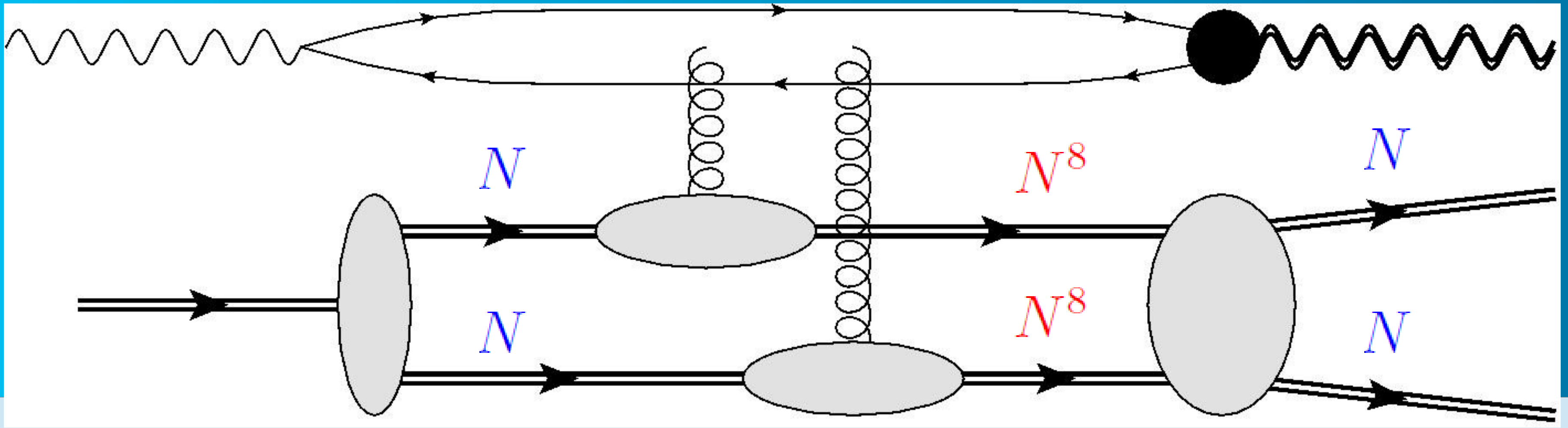
New feature
octet-octet* to
NN
New way to study NN force



Summary



- Through diffraction, a high-energy EIC can be used to study lower-energy nuclear physics.
- High-$p_\perp$ breakup of a deuteron can be used to measure interesting NN scattering channels.



- Diffraction is sensitive to exotic NN physics, including “hidden color” octet nucleons.
- Even if only conventional NN physics is accessible, the process is definitely measurable at an EIC and can discriminate between Landshoff and Brodsky-Farrar mechanisms.
- A wide variety of similar processes in nuclei can be studied at the EIC.